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Canadian Science Advisory Secretariat
Science Advisory Report 2014/039

STOCK ASSESSMENT AND HARVEST ADVICE FOR ROCK SOLE (*LEPIDOPSETTA SPP.*) IN BRITISH COLUMBIA

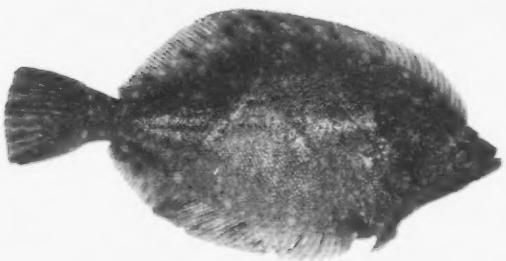

Image : Rock Sole (Lepidopsetta spp.): Photo Credit: Terri Bonnet, Fisheries and Oceans Canada (DFO).

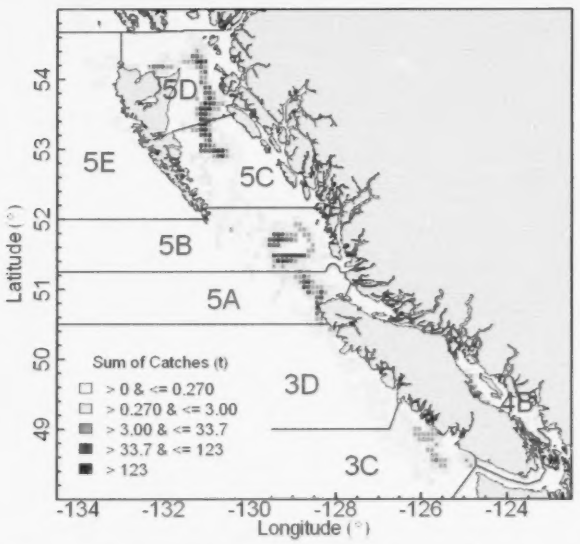

Figure 1. Sum of Rock Sole catches (tonnes) from trawl fisheries between 1996 and 2012 in grid cells 0.100 longitude by 0.075 latitude (roughly 58.6 km^2). DFO major Statistical Areas that were used as a basis for stock assessment are shown.

Context:

Rock Sole (Lepidopsetta spp.) is a commercially important species of flatfish in British Columbia, Canada. An updated stock assessment was required to characterize stock status relative to reference points consistent with the Fisheries and Oceans Canada 'Fishery Decision-making Framework Incorporating the Precautionary Approach'. Harvest advice was also requested in the form of decision tables that forecast the impacts of varying harvest levels on stock status.

Assessment and harvest advice were provided for two management areas in BC: Areas 5CD (Hecate Strait) and 5AB (Queen Charlotte Sound). Key results from the stock assessment are summarized in this Science Advisory Report.

This Science Advisory Report is from the Regional Peer Review meeting on 'Assessments of British Columbia Rock Sole and Silvergray Rockfish Stocks', held on November 20-22, 2013. The full Research Document describing this stock assessment and the Proceedings from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Canada

SUMMARY

- Rock Sole (*Lepidopsetta spp.*) is a commercially important flatfish that occurs along the entire coast of British Columbia, Canada. Abundance is highest in Queen Charlotte Sound (Area 5AB) and Hecate Strait (Area 5CD), which is where the majority of Rock Sole catch is taken. Catch is almost entirely taken by the groundfish trawl fishery.
- Rock Sole stocks in Areas 5AB and 5CD are assessed as two independent stocks using a female-only, catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities. Limited fishery and survey data from the other three management areas (3CD, 4B, 5E) preclude the provision of quantitative harvest advice for these areas.
- Female spawning biomass in Area 5AB at the start of 2014 (B_{2014}) is estimated to be 0.37 (0.27 - 0.49) of unfished female spawning biomass (B_0), where numbers denote median (and 5-95 percentiles) of the Bayesian results. B_{2014} is estimated to be 1.52 (0.98 - 2.26) of the female spawning biomass associated with maximum sustainable yield (B_{MSY}). In Area 5CD, B_{2014} is estimated to be 0.80 (0.58 – 1.07) of B_0 and 3.22 (2.10 – 4.64) of B_{MSY}.
- Stock status is evaluated relative to reference points that are consistent with the provisional reference points contained in the DFO 'Fishery Decision-making Framework Incorporating the Precautionary Approach'. These include a limit reference point (LRP = $0.4B_{MSY}$), an upper stock reference point (USR = $0.8B_{MSY}$), B_{MSY}, and the harvest rate associated with maximum sustainable yield, u_{MSY}. A set of historical reference points that were previously developed and applied to British Columbia Rock Sole stocks in 2006 are also used, which include a limit biomass (B_{LIM}), a target biomass (B_{TAR}), current biomass (B_{2014}), and a target harvest rate (u_{TAR}).
- In Area 5AB, the model estimates the probabilities that B_{2014} is greater than $0.4B_{MSY}$, $0.8B_{MSY}$, B_{MSY}, B_{LIM} and B_{TAR} to be 100%, 99%, 94%, 100% and 41%, respectively. The model estimates the probabilities that the harvest rate in 2013 was less than u_{TAR} and less than u_{MSY} to both be 100%.
- In Area 5CD, the model estimates the probabilities that B_{2014} is greater than $0.4B_{MSY}$, $0.8B_{MSY}$, B_{MSY}, B_{LIM} and B_{TAR} to be 100%, 100%, 100%, 100% and 95%, respectively. The model estimates the probabilities that the harvest rate in 2013 was less than u_{TAR} and less than u_{MSY} to both be 100%.
- Advice to management is presented in the form of decision tables using five-year projections for a range of constant catches. In Area 5AB, a constant catch of 330 tonnes (males and females combined), which is just below the recent average annual catch, has a 98% probability of maintaining stock size above B_{MSY} by 2019. Stock size is predicted to likely decrease at catch levels of 550 tonnes and higher.
- Harvest advice for Area 5CD shows that a constant catch of 670 tonnes (males and females combined), which is just above the recent average annual catch, has a 100% probability of maintaining stock size above B_{MSY} by 2019. Stock size is predicted to likely decrease at catch levels of 900 tonnes and higher.

INTRODUCTION

Rock Sole (*Lepidopsetta spp.*) is a commercially important flatfish that occurs along the entire coast of British Columbia (BC), Canada (Image; Figure 1). Two species of Rock Sole occur in BC: Southern Rock Sole (*L. bilineata*) and Northern Rock Sole (*L. polyxystra*). These two species are similar in appearance, and were believed to be a single species prior to 2000. A

large majority of the Rock Sole encountered in BC fisheries and research surveys are believed to be Southern Rock Sole because observations of Northern Rock Sole in BC have been rare. In addition, Northern Rock Sole in Alaska tend to occur in bays and inlets, while Southern Rock Sole are more frequently found further offshore (Stark and Somerton 2002), which is where trawl fishery catch in BC occurs. Rock Sole stocks are referred to at the genus level in this assessment to allow for possibility that some Northern Rock Sole occur in catch and survey samples.

Rock Sole in BC are assessed and managed as five separate areas based on DFO Major Statistical Areas (Figure 1). These areas include the Strait of Georgia (Area 4B), west coast Vancouver Island (Area 3CD), Queen Charlotte Sound (Area 5AB), Hecate Strait (Area 5CD) and west coast Haida Gwaii (Area 5E). Rock Sole abundance in BC is highest in Hecate Strait and Queen Charlotte Sound, which is where the majority of catches are taken. Most catch is taken by the groundfish trawl fishery, with very small numbers taken by hook-and-line fisheries.

Total allowable catch (TAC) limits exist for three of the five management areas in BC (3CD, 5AB, 5CD), with a combined annual TAC of 1,425 tonnes over the last three years. Ninety-three percent (93%) of this total TAC is allocated to 5AB and 5CD (Figure 2). TACs are not set for the remaining two management areas due to low catches. The average total coastwide catch over the last three years, including discards, is 1,088 tonnes. In Area 5AB, 98% of commercial trawl fishery captures of Rock Sole occur at a depth range of 53-210 metres. In Area 5CD, the equivalent depth range is 27-146 metres.

This assessment provides harvest advice for Areas 5AB and 5CD. Limited fishery and survey data from the other three management areas (3CD, 4B, 5E) preclude the provision of quantitative harvest advice for those areas.

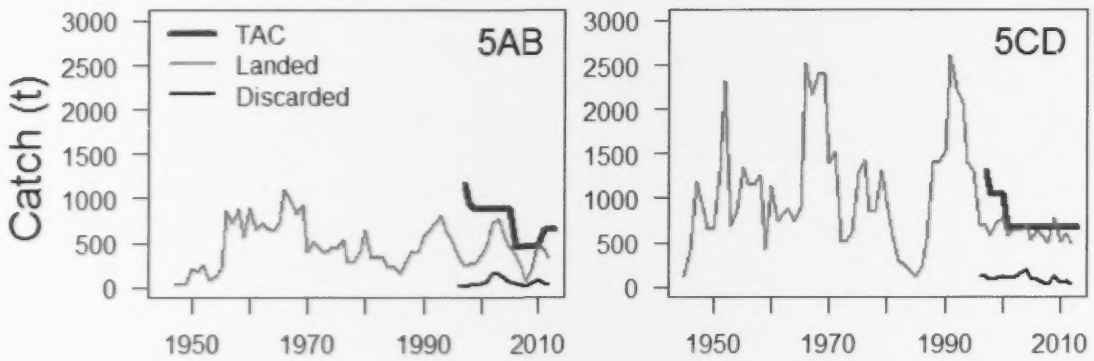

Figure 2: Annual trawl fishery trends in Rock Sole landings, discards, and TAC for Areas 5AB and 5CD. All units are in tonnes. Landings from 1945-1955 are limited to Canadian fisheries, landings from 1956-1981 include both Canadian and U.S. fisheries, and landings from 1982-2012 include only Canadian fisheries. Reliable discard records were only available following implementation of 100% at-sea observer coverage of the trawl fishery in 1996. Discards prior to 1996 were estimated for input into stock assessment models.

ASSESSMENT

Methods

A female-only statistical catch-at-age model in a Bayesian estimation framework was used to assess Rock Sole in Areas 5AB and 5CD. Bayesian estimation was done using the Markov Chain Monte Carlo (MCMC) method. For each area, the model was fitted to catch data, two or

more indices of abundance with associated coefficients of variation, and age composition data from commercial trawl fisheries and research surveys.

Trawl fishery landing data were available from 1945 to 2012 for input into the models. As only the female portion of the population was modelled, all catch data were scaled to represent female-only catch (including estimated discards) before input into the model.

Indices of abundance included survey indices and commercial catch-per-unit-effort (CPUE) series. CPUE series were standardized using a stepwise generalized linear model procedure. For Area 5CD, the CPUE series was split into two abundance indices (pre-1996 and 1996+) to reflect substantial fishery management changes that occurred in 1996, including the implementation of Individual Vessel Quota (IVQ) management and the introduction of 100% observer coverage. Independent catchability coefficients were modelled for each time period. For Area 5AB, a single CPUE abundance index with a single catchability coefficient was used to represent the entire time period of available data (1966 – 2012). While the approach taken in Area 5CD of splitting the time series at 1996 was originally deemed preferable to using a single CPUE series, model runs that uncoupled the CPUE series in Area 5AB were discredited due to unlikely parameter estimates.

Parameters estimated by the stock assessment model included unfished equilibrium recruitment, stock recruitment steepness, natural mortality (Area 5CD only), catchability coefficients for abundance indices, and selectivity parameters for the commercial fishery and survey indices. In Area 5AB, the rate of natural mortality was held fixed because the MCMC parameter search did not converge when natural mortality was estimated.

All calculations, including reference point estimation and harvest decision tables, were made using the Bayesian MCMC method to quantify the uncertainty associated with parameter estimation. This approach yielded 1,000 MCMC samples from the Bayesian posterior distribution. Estimates of various quantities were calculated from these samples, and are presented here as median values (with 5-95% percentiles). Results presented as probability statements were also calculated using the 1,000 MCMC samples.

Quantities related to maximum sustainable yield (MSY), such as the spawning biomass associated with MSY, B_{MSY}, and the harvest rate associated with MSY, u_{MSY}, were estimated by projecting assessment model fits forward across a range of constant harvest rates until equilibrium was reached.

Harvest decision tables for Areas 5AB and 5CD were created by projecting each assessment model 5 years into the future under a range of constant catch levels without feedback control. For each level of constant harvest, decision tables show the probability that projected stock status in each year will be greater than each of the specified reference points.

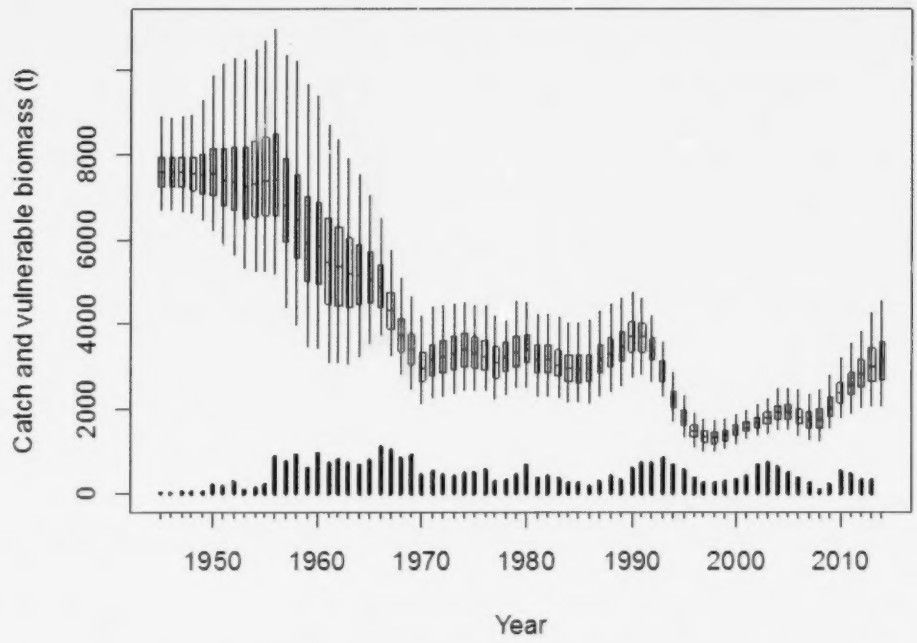

Figure 3. Annual commercial catch of female Rock Sole (vertical bars) and vulnerable female biomass (boxplots showing 2.5, 25, 50, 75 and 97.5 percentiles of the MCMC results) for Area 5AB.

Results

Predicted female vulnerable biomass in Area 5AB showed a steep decline from unfished 1945 levels between the late 1950s and 1970 (Figure 3). Biomass levels stabilized between 1970 and 1990, which was a period of reduced catch compared to the 1960s, before once again beginning to decline in the early 1990s with increased catches. Biomass levels reached low points in 1997 and 1998, and then generally increased to current levels. Female spawning biomass in Area 5AB at the start of 2014 was estimated to be at 0.37 (0.27 – 0.49) of unfished female spawning biomass in 1945 (B_0; Table 1).

Predicted female vulnerable biomass in Area 5CD showed an initial increase in biomass to levels greater than the unfished 1945 biomass during the early 1950s, followed by a continuous decline during the 1960s (Figure 4). The steepest decline occurred in the late-1960s, a time during which annual catches doubled. Biomass levels experienced minor fluctuations between 1970 and 2000. Biomass in Area 5CD has shown a general increasing trend since 2000, with the greatest rate of increase occurring between 2000 and 2005. Female spawning biomass in Area 5CD at the start of 2014 is estimated to be 0.80 (0.58 – 1.07) of B_0 (Table 1).

Stock assessment models in both areas estimated occasional periods of increased recruitment throughout the modelled time series, with the timing of these periods coinciding in 5AB and 5CD. Periods of increased recruitment occurred in the late 1980s (1984-1989 in 5AB; 1988-1989 in 5CD) and in 1999-2001. A more recent increase in recruitment was also estimated (2006-2008 for Area 5AB; 2007-2009 for Area 5CD); however, the nature of this increase is less certain than those in earlier years as fish from these age classes were just beginning to appear in the fishery and the survey samples as 3 to 5 year-olds. Strong recruitment events around 2000 and between 2006 and 2009 coincided with the increasing biomass trend estimated in both areas since 2000 (Figures 3 and 4).

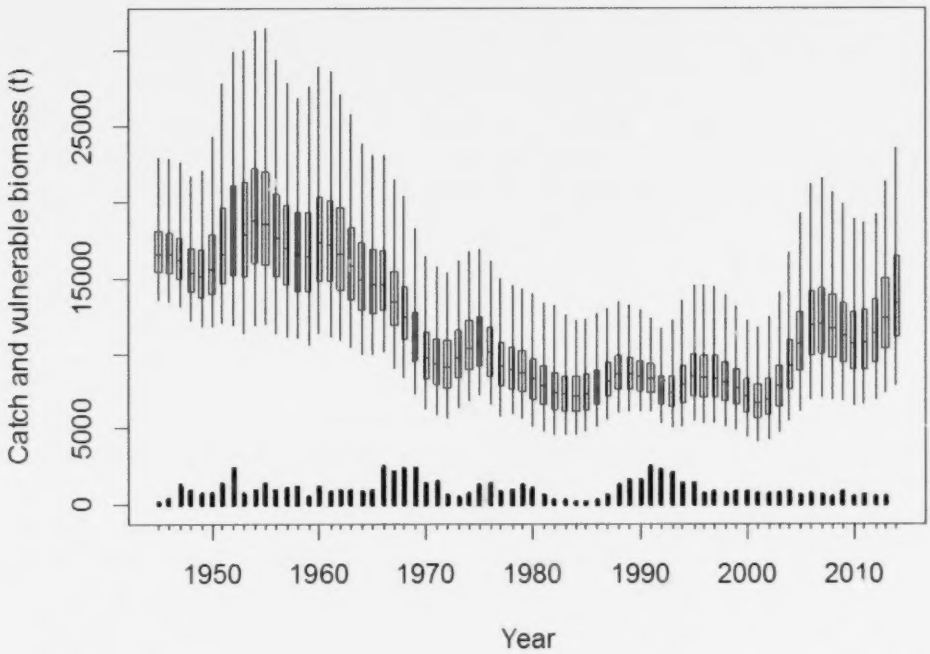

Figure 4. Annual commercial catch of female Rock Sole (vertical bars) and vulnerable biomass (boxplots showing 2.5, 25, 50, 75 and 97.5 percentiles of the MCMC results) for Area 5CD.

Estimated exploitation rates in both areas increased in the late 1960s, with median rates during this period reaching around 0.25 in 5AB and around 0.20 in 5CD. After a period of decline, exploitation rates began to increase again in the late 1980s, with rates peaking at over 0.30 in both areas in the early 1990s. Estimated trends in exploitation rates diverged between the two areas starting in the late 1990s. In Area 5AB, rates experienced moderate declines in the late 1990s before once again increasing to a historical peak of approximately 0.40 in 2003-2004. Exploitation rates dropped steeply in Area 5AB after 2004, with the exploitation rate in 2013, u_{2013}, estimated to be 0.11 (0.08-0.15). In contrast, median exploitation rates in Area 5CD have remained at or below 0.12 since 1996. For Area 5CD, u_{2013} was estimated to be 0.04 (0.03-0.06).

Estimates of MSY-based quantities are given in Table 1. For Area 5AB, the estimated median female-only MSY is 524 (483-580) tonnes, compared to an average female catch of 316 tonnes over the last five years (2008-2012). For Area 5CD, the estimated median female-only MSY is 1,895 (1,326-2,810) tonnes, compared to an average female catch of 577 tonnes over the last five years. The estimated median values of B_{2014}/B_{MSY} are 1.52 (0.98-2.26) for Area 5AB and 3.22 (2.10-4.65) for Area 5CD.

Reference Points

Two approaches to setting stock reference points for Areas 5AB and 5CD are presented in decision tables for this assessment: MSY-based reference points and historical reference points based on reconstructed biomass and exploitation rate trajectories. Both types of reference points were calculated from assessment model fits.

Table 1. The 5th, 50th and 95th percentiles of the MCMC results for management parameters and associated quantities for the Area 5AB and Area 5CD assessments. B denotes female spawning biomass, V denotes female vulnerable biomass, B_0 (V_0) denotes unfished female spawning (vulnerable) biomass, MSY denotes maximum sustainable yield, u denotes harvest rate. B_{LIM} represents the historical limit biomass, B_{TAR} represents the historical target biomass, and u_{TAR} represent the historical target harvest rate (defined in text). All biomass units are in tonnes.

	5AB			5CD		
	Percentile			Percentile		
Value	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_0	6,765	7,749	8,457	16,263	19,329	25,361
B_{2014}	1,977	2,776	3,779	9,949	15,385	24,724
V_{2014}	2,185	3,122	4,344	8,399	13,341	21,310
B_{2014} / B_0	0.271	0.371	0.492	0.581	0.802	1.068
V_{2014} / V_0	0.298	0.411	0.549	0.577	0.802	1.078
u_{2013}	0.082	0.110	0.150	0.025	0.039	0.061
MSY-based quantities						
B_{MSY}	1,427	1,833	2,471	3,613	4,853	6,799
B_{MSY} / B_0	0.202	0.246	0.296	0.201	0.248	0.308
B_{2014} / B_{MSY}	0.977	1.521	2.264	2.100	3.223	4.638
$0.4B_{MSY}$	571	733	988	1,445	1,941	2,720
$0.8B_{MSY}$	1,142	1,467	1,977	2,890	3,883	5,439
MSY	483	524	580	1,326	1,895	2,810
u_{MSY}	0.176	0.239	0.307	0.295	0.507	0.800
u_{2013}/u_{MSY}	0.299	0.463	0.724	0.037	0.077	0.163
Historical quantities						
B_{LIM}	863	1,133	1,422	5,223	7,739	11,971
B_{2014} / B_{LIM}	1.862	2.452	3.260	1.528	2.004	2.722
B_{TAR}	2,216	2,879	3,663	7,753	11,135	16,662
B_{2014} / B_{TAR}	0.738	0.959	1.271	1.000	1.401	1.969
u_{TAR}	0.154	0.188	0.229	0.083	0.122	0.168
u_{2013}/ u_{TAR}	0.464	0.590	0.750	0.243	0.319	0.423

The MSY-based reference points are consistent with the provisional recommendations contained in the DFO Fishery Decision-making Framework Incorporating the Precautionary Approach (DFO 2009), and include:

(i) a Limit Reference Point (LRP) set at $0.4B_{MSY}$,

(ii) an Upper Stock Reference (USR) set at $0.8B_{MSY}$,

(iii) B_{MSY}, and

(iv) a harvest rate associated with MSY, u_{MSY}.

Historical reference points were previously developed and applied to Rock Sole in 2006 (DFO 2006). They include:

(v) a limit biomass level set at the minimum biomass estimate between 1966 and 2005 (B_{LIM}),

(vi) a target biomass level set at the average biomass estimate during a period of average biomass levels (1977-1985 for 5AB; 1971-1980 for 5CD; B_{TAR}),

(vii) a target harvest rate based on the average harvest rate between 1966 and 2005 (u_{TAR}), and

(viii) biomass in the current year, B_{2014}.

Based on medians, the Area 5AB stock was estimated to have remained around B_{TAR} throughout the 1970s and 1980s before declining to B_{LIM} in the mid-1990's (Figure 5). Since this

historical low, the 5AB stock increased to just below B_{TAR} at the start of 2014. The full Bayesian results give a 100% probability that B_{2014} is above B_{LIM} and a 41% probability that B_{2014} is above B_{TAR}. Based on medians, female spawning biomass in Area 5AB was estimated to have been above the LRP ($0.4B_{MSY}$) throughout the modelled time period, and above the USR ($0.8B_{MSY}$) for all years except 1995 to 2006 (Figure 5). There is a 100% probability that B_{2014} is above the LRP and a 99% probability that B_{2014} is above the USR.

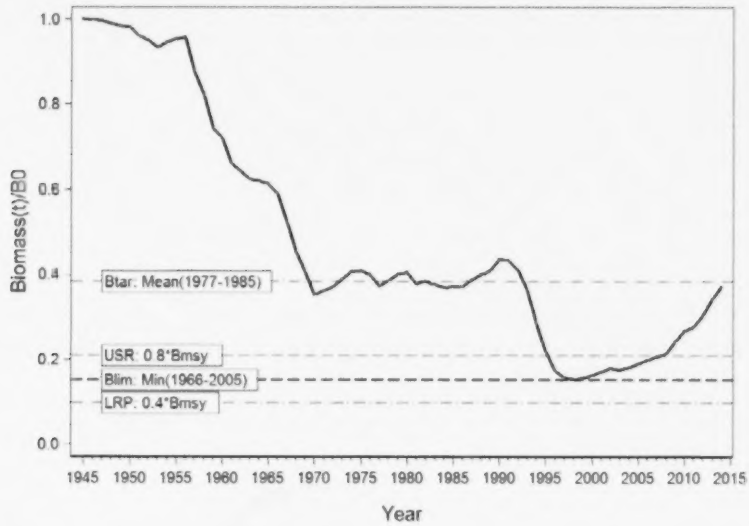

Figure 5. Median estimates of female spawning biomass relative to B_0 by year for the 5AB base case (black line). Also shown are median estimates of MSY-based reference points (LRP= $0.4B_{MSY}$; USR = $0.8B_{MSY}$) relative to B_0 and median estimates of historical reference points (B_{LIM} = minimum biomass between 1966 and 2005; B_{TAR} = mean biomass between 1977 and 1985) relative to B_0.

Based on medians, the Area 5CD stock was estimated to have dropped below B_{TAR} for the first time in the early 1970s and then fluctuated between B_{TAR} and B_{LIM} throughout the late-1970s to mid-2000s (Figure 6). Female spawning biomass in Area 5CD increased to above B_{TAR} in 2004 and continued to increase since then. The full Bayesian results give a 100% probability that B_{2014} is above B_{LIM} and a 95% probability that B_{2014} is above B_{TAR}. Female spawning biomass remained above both the USR and LRP for the entire modelled time period based on median estimates. There is a 100% probability that B_{2014} is above both the LRP and the USR in Area 5CD.

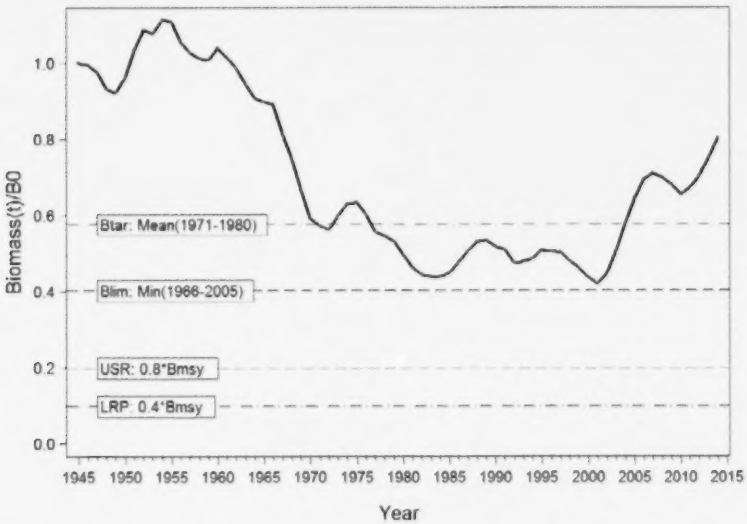

Figure 6. Median estimates of female spawning biomass relative to B_0 by year for the 5CD base case (black line). Also shown are median estimates of MSY-based reference points (LRP = $0.4B_{MSY}$; USR = $0.8B_{MSY}$) relative to B_0 and median estimates of historical reference points (B_{LIM} = minimum biomass between 1966 and 2005; B_{TAR} = mean biomass between 1971 and 1980) relative to B_0.

Figure 7 shows stock status relative to the provisional DFO (2009) LRP and USR reference points. These two reference points demarcate critical, cautious and healthy zones (DFO 2009).

There was a 100% probability that, in each area, exploitation rates in 2013 were less than u_{TAR} and u_{MSY}. In Area 5AB, the ratio of u_{2013} / u_{TAR} was 0.59 (0.46-0.75) and the ratio of u_{2013} / u_{MSY} was 0.46 (0.30-0.72). In Area 5CD, the ratio of u_{2013} / u_{TAR} was 0.32 (0.24-0.42) and the ratio of u_{2013} / u_{MSY} was 0.08 (0.04-0.16).

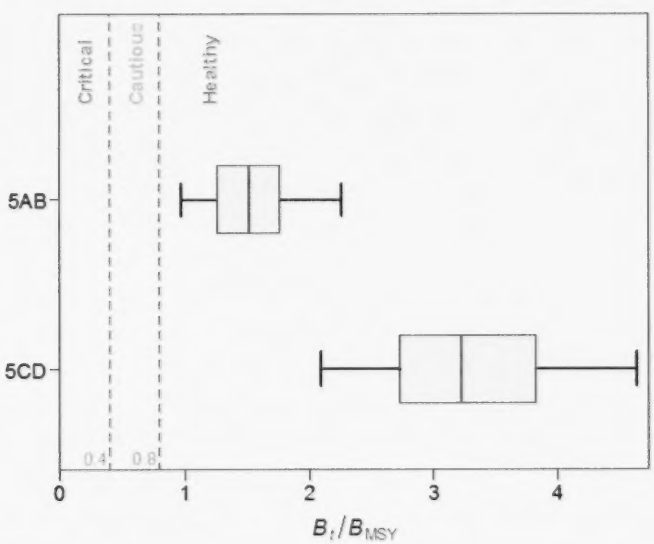

Figure 7. Current stock status (represented as the ratio of B_{2014} to B_{MSY}) of Area 5CD and 5AB stocks relative to the DFO Precautionary Approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$. Boxplots show the 5, 25, 50, 75 and 95 percentiles from the MCMC results.

Projection Results and Decision Tables

Projections starting with the biomass at the beginning of 2014 were made over a range of constant catch levels without feedback controls for a five-year period (Tables 2 and 3). Catch levels in decision tables are shown as the female catch used to drive projections of the female-only model, and the corresponding total catch that has been adjusted to include males and females based on the long-term average proportion of females in the catch.

Decision tables give the probabilities of the female spawning biomass remaining above the reference points in 2019 for each catch level. Note that catches are held constant, so there is no consequent reduction in exploitation rate if a stock reaches the cautious or critical zones in projections. As an example of how to read the tables, the estimated probability that the 5AB stock will be above $0.4B_{MSY}$ in 2019 under a constant annual female catch of 600 tonnes is 96% (i.e., $P(B_{2019} > 0.4B_{MSY}) = 0.96$ in the row in Table 2 beginning with 600 t of female catch).

In Area 5AB, a constant catch of 330 tonnes (males and females combined), which is just below the recent average annual catch of 346 tonnes, has a 98% probability of maintaining stock size above B_{MSY} at the beginning of 2019 (Table 2). Stock size is predicted to likely decrease (i.e. >50% probability) below the 2014 level at constant catches of 550 tonnes and higher.

In Area 5CD, a constant catch of 670 tonnes (males and females combined), which is just above the recent average annual catch of 636 tonnes, has a 100% probability of maintaining stock size above B_{MSY} at the beginning of 2019. Stock size is predicted to likely decrease below the 2014 level at constant catches of 900 tonnes and higher.

Summary of Non-Assessed Areas

Rock Sole catches from commercial fisheries and research surveys in Areas 3CD (west coast Vancouver Island), 4B (Strait of Georgia), and 5E (west coast Haida Gwaii) have historically been low and infrequent. As a result, no attempts were made to fit a population model to data from these three areas.

In Area 3CD, annual Rock Sole landings peaked at 242 tonnes in 1989. A large reduction in landings occurred in 1996 coincident with the implementation of at-sea observers and just before the start of the IVQ program in 1997. This decline in landings was also coincident with a substantial decline in Pacific Cod fishing effort and landings, which may have meant less Rock Sole effort, either directed or taken as bycatch. Landings in Area 3CD over the last five years have averaged 16 tonnes per year, which is well below the assigned TAC of 102 tonnes for this area. Rock Sole TACs have never been assigned for Areas 4B and 5E. In Area 4B, Rock Sole landings have averaged 6 tonnes per year over the last five years. In Area 5E, Rock Sole landings have averaged less than 0.05 tonnes per year over the past five years.

No harvest advice is provided to managers for these areas. Fishery statistics should be monitored at regular intervals to assess whether Rock Sole catch shows any substantial changes that would warrant a request for harvest advice.

Sources of Uncertainty

Uncertainty in estimated parameters and associated management quantities is expressed using Bayesian estimation; however this approach only captures parameter uncertainty. It does not characterize structural uncertainty in the assessment model. Sensitivity analyses were used to investigate how choices of model formulation affected results. None of the sensitivity scenarios considered changed the perception that Rock Sole stocks in both areas were most likely above B_{MSY}.

Table 2. Decision table for 5-year projections in Area 5AB. Values are the probability that female spawning biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2019 under a given constant annual catch policy. Female catch represents the constant catch (including discards) value used in projections of the female-only model, while total catch represents an adjusted catch value to include males and females (including discards). Total catch was estimated by dividing female catch by the median proportion of total catch that was female between 1956–73, 1975–2006, and 2009 (91.04%). For reference, the average total catch over the last 5 years (2008-2012) is 346 tonnes and the maximum annual total catch between 1945 and 2012 was 1,102 tonnes in 1966.

Female Catch	Total Catch	$P(B_{2019} > 0.4B_{MSY})$	$P(B_{2019} > 0.8B_{MSY})$	$P(B_{2019} > B_{MSY})$	$P(B_{2019} > B_{2014})$	$P(u_{2019} > u_{MSY})$	$P(B_{2019} > min(B_{1966\text{-}2005}))$	$P(B_{2019} > mean(B_{1977\text{-}1985}))$	$P(u_{2019} > mean(u_{1966\text{-}2005}))$
0	0	1.00	1.00	1.00	1.00	0.00	1.00	0.99	0.00
100	110	1.00	1.00	1.00	1.00	0.00	1.00	0.98	0.00
200	220	1.00	1.00	0.99	0.98	0.00	1.00	0.90	0.00
300	330	1.00	1.00	0.98	0.85	0.00	1.00	0.76	0.00
400	440	1.00	0.97	0.92	0.62	0.03	1.00	0.55	0.07
500	550	1.00	0.91	0.81	0.36	0.20	0.97	0.36	0.40
600	660	0.96	0.77	0.60	0.19	0.53	0.92	0.20	0.77
700	770	0.88	0.56	0.40	0.08	0.79	0.75	0.11	0.94
800	880	0.71	0.38	0.26	0.03	0.92	0.54	0.05	0.98
900	990	0.49	0.22	0.14	0.01	0.97	0.32	0.03	0.99
1000	1100	0.31	0.12	0.07	0.01	0.99	0.18	0.01	1.00
1100	1210	0.19	0.06	0.03	0.01	0.99	0.09	0.01	1.00
1200	1320	0.10	0.03	0.01	0.00	1.00	0.05	0.00	1.00

Table 3. Decision table for 5-year projections in Area 5CD. Values are the probability that female spawning biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2019 under a given constant annual catch policy. Female catch represents the constant catch (including discards) value used in projections of the female-only model, while total catch represents an adjusted catch value to include males and females (including discards). Total catch was estimated by dividing female catch by the median proportion of total catch that was female between 1956 and 2009 (88.95%). For reference, the average total catch over the last 5 years (2008-2012) is 636 tonnes and the maximum annual total catch between 1945 and 2012 was 2,643 tonnes in 1991.

Female Catch	Total Catch	$P(B_{2019} > 0.4B_{MSY})$	$P(B_{2019} > 0.8B_{MSY})$	$P(B_{2019} > B_{MSY})$	$P(B_{2019} > B_{2014})$	$P(u_{2019} > u_{MSY})$	$P(B_{2019} > min(B_{1966\text{-}2005}))$	$P(B_{2019} > mean(B_{1971\text{-}1980}))$	$P(u_{2019} > mean(u_{1966\text{-}2005}))$
0	0	1.00	1.00	1.00	0.83	0.00	1.00	0.99	0.00
100	110	1.00	1.00	1.00	0.79	0.00	1.00	0.98	0.00
200	220	1.00	1.00	1.00	0.76	0.00	1.00	0.98	0.00
300	340	1.00	1.00	1.00	0.72	0.00	1.00	0.97	0.00
400	450	1.00	1.00	1.00	0.67	0.00	1.00	0.97	0.00
500	560	1.00	1.00	1.00	0.62	0.00	1.00	0.96	0.00
600	670	1.00	1.00	1.00	0.57	0.00	1.00	0.93	0.00
700	790	1.00	1.00	1.00	0.51	0.00	1.00	0.91	0.00
800	900	1.00	1.00	1.00	0.45	0.00	1.00	0.90	0.00
900	1010	1.00	1.00	1.00	0.40	0.00	0.99	0.88	0.02
1000	1120	1.00	1.00	1.00	0.35	0.00	0.99	0.85	0.05
1100	1240	1.00	1.00	1.00	0.31	0.00	0.99	0.83	0.14
1200	1350	1.00	1.00	1.00	0.28	0.00	0.98	0.79	0.25
1300	1460	1.00	1.00	1.00	0.23	0.00	0.97	0.76	0.39
1400	1570	1.00	1.00	1.00	0.19	0.01	0.97	0.72	0.54
1500	1690	1.00	1.00	0.99	0.17	0.01	0.95	0.68	0.67
1750	1970	1.00	0.99	0.98	0.11	0.05	0.90	0.58	0.88
2000	2250	1.00	0.98	0.95	0.07	0.10	0.83	0.49	0.96
2250	2530	1.00	0.95	0.91	0.04	0.18	0.73	0.39	0.99
2500	2810	0.99	0.91	0.87	0.03	0.28	0.64	0.30	1.00
2750	3090	0.97	0.86	0.80	0.02	0.40	0.54	0.23	1.00
3000	3370	0.96	0.81	0.72	0.01	0.50	0.46	0.18	1.00

The use of fishery CPUE is a key source of uncertainty in the Area 5AB and Area 5CD assessments. An assumption of both analyses is that the commercial CPUE series are proportional to the vulnerable biomass of Rock Sole. While commercial CPUE can track biomass, it can also be influenced by factors that affect fishing behaviour, including management regulations, fishing opportunities for co-occurring species, and changes in fishing-gear efficiency. CPUE indices are also prone to hyperstability, in which CPUE remains high despite declining abundance. While CPUE data are not the preferred source of abundance information for fitting stock assessment models, they are the only long-term index series available for Rock Sole stocks in BC. Violations of the assumption that CPUE is proportional to stock biomass could cause misleading assessment results.

Assessment results in Area 5AB are less credible than those in Area 5CD for two reasons. First, it was necessary to assume a constant CPUE catchability coefficient in 5AB over the years 1966 to 2012. This assumption is expected to be violated given a substantial change in management practices starting in 1996 (described above). Second, the 5AB model estimated a high survey catchability coefficient for the Queen Charlotte Sound synoptic survey, which lacks credibility because the gear used for this survey is sub-optimal for flatfish. Furthermore, the catchability coefficient for the Queen Charlotte Sound synoptic survey was estimated to be three times higher than that of the Hecate Strait synoptic survey in the more data-rich Area 5CD, which uses the same gear and survey design as the Queen Charlotte Sound synoptic survey.

Ecosystem Considerations

In 2012, measures were introduced to reduce and manage the bycatch of corals and sponges by the British Columbia groundfish bottom trawl fishery. These measures were developed jointly by industry and environmental non-governmental organisations, and include:

(i) limiting the footprint of groundfish bottom trawl activities,

(ii) establishing a combined bycatch conservation limit for corals and sponges, and

(iii) establishing an encounter protocol for individual trawl tows when the combined coral and sponge catch exceeds 20 kg.

These measures have been incorporated into DFO's Pacific Region Groundfish Integrated Fisheries Management Plan (March 28, 2012, version 2.1).

The fishery is also subject to the following management measures: 100% at-sea monitoring, 100% dockside monitoring, individual vessel accountability for all retained and released catch, individual transferable quotas and reallocation of these quotas between vessels and fisheries to cover catch of non-directed species (see aforementioned Management Plan).

CONCLUSIONS AND ADVICE

Stock assessments for Rock Sole in Areas 5AB and 5CD characterize two stocks that underwent initial biomass reductions during the 1950s and/or 1960s from an assumed unfished equilibrium biomass in 1945. Biomass in both areas stabilized during the 1980s when there were decreased catch levels. While the Area 5AB stock underwent further biomass declines in the 1990s, the 5CD stock remained relatively stable. Since 2000, biomass in both areas generally increased. Both stocks are estimated to have high probabilities of current biomass being above B_{MSY}, and of current exploitation rates being below u_{MSY}. The Area 5AB stock is most likely just below the historical target biomass level established for this stock in 2006, while the Area 5CD stock has a high probability of being above the Area 5CD historical target biomass level.

Advice to management is provided in the form of decision tables created by projecting each assessment model 5 years into the future under a range of different constant catch levels

without feedback control. For each level of constant harvest, decision tables show the probability that projected stock status in each year will be greater than the specified reference points.

SOURCES OF INFORMATION

This Science Advisory Report is from the Regional Peer Review meeting on 'Assessments of British Columbia Rock Sole and Silvergray Rockfish Stocks', held on November 20-22, 2013. Additional publications from thismeeting (Proceedings and Research Documents) will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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